

Training session on Regional Climate Model Evaluation System (RCMES)

Kyo Lee (huikyo.lee@jpl.nasa.gov)

(Jet Propulsion Laboratory, California Institute of Technology)

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<http://rcmes.jpl.nasa.gov>

<http://climate.apache.org>

Acknowledgement

- My special thanks of gratitude to Dr. Sanjay, Dr. Krishnan, Dr. Neena, and Dr. Suhas.
- Regional Climate Model Evaluation System (RCMES) team
Duane Waliser (PI), Huikyo Lee (co-I), Alexander Goodman, Peter Gibson, Elias Massoud, Brian Wilson, Paul Loikith², and Antonio Monge³
¹JPL/Caltech, ²California State U. LA, ³Portland State U.
- **Virtual Information-Fabric Infrastructure (VIFI)** team led by Prof. William Tolone at U. of North Carolina, Charlotte
- Parallelized BCSD codes from Dr. TJ Vandal and NASA Earth eXchange (NEX) team at NASA Ames center

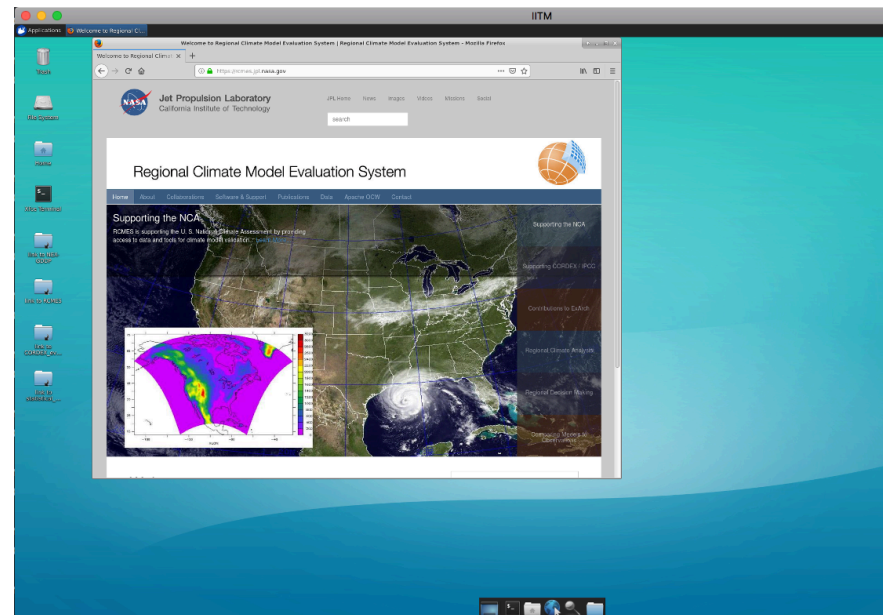
RCMES Training Outline (10:00-12:30)

Time	Agenda Item	Process/presentations/materials
10:00-10:15	Welcome and connect to Amazon Elastic Compute Cloud (EC2)	<ul style="list-style-type: none"> Check the IP address of the assigned server Connect to the server using Microsoft Remote Desktop (or terminal software)
10:15-10:30	Activity #1 : Correct biases in CORDEX RCM simulations	<ul style="list-style-type: none"> Quantile-based bias correction of the CORDEX WAS simulations using satellite-based precipitation observation data
10:30-10:50	Activity #2 : Evaluate CORDEX RCM simulations	<ul style="list-style-type: none"> Systematic evaluation of CORDEX RCMs against obs4mips using RCMES
Break (10:50-11:00)		
11:00-11:30	Activity #3 : Pointwise Statistical downscaling using RCMES	<ul style="list-style-type: none"> CMIP5 temperature and precipitation datasets for present and future climate Compare the IPCC climate change scenarios (RCP 4.5 vs. RCP 8.5)
11:30-11:45	Activity #4 : Download and visualize the NEX-GDDP data	<ul style="list-style-type: none"> NASA Earth Exchange Globally Daily Downscaled Projections (NEX-GDDP) in Amazon Simple Storage Service (S3)
11:45-	Activity #5	<ul style="list-style-type: none"> Analyze the bias corrected RCM output and check the evaluation result

Two different ways to connect to the virtual Linux machine on Amazon Web Service

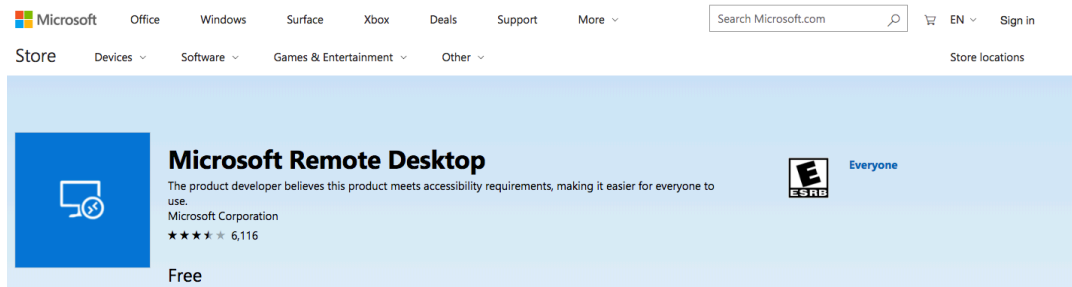
- SSH connection using your terminal application
- Prerequisite software
 - terminal: putty, xshell, xterm
 - X Server: Xming, XQuartz
 - NetCDF/HDF viewer: Panoply
 - (Optional) sftp client: xftp, FileZilla
- `ssh -Y user1@xx.xxx.xx.xxx`
- password: **cordex**

- Remote desktop



Prerequisite software to run remote desktop

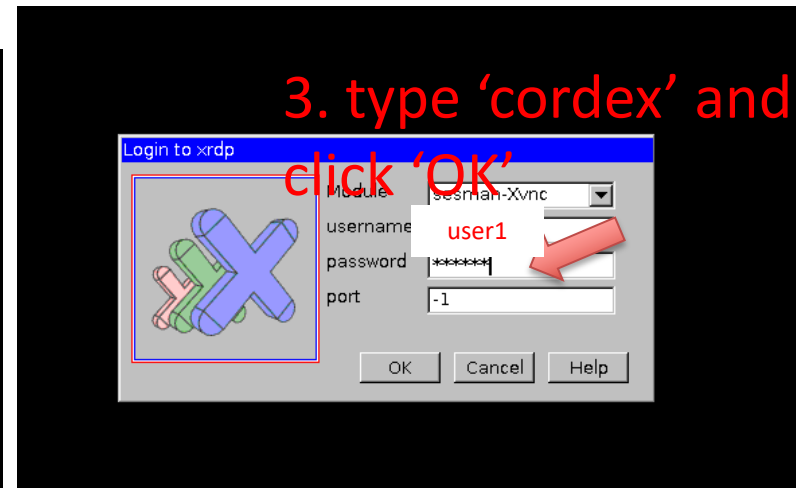
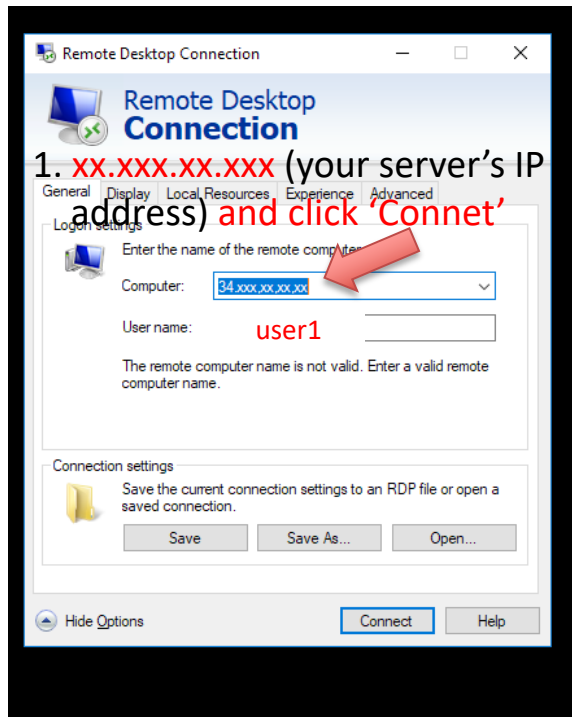
- ~~Linux based system~~
- Windows laptops: Microsoft Remote Desktop



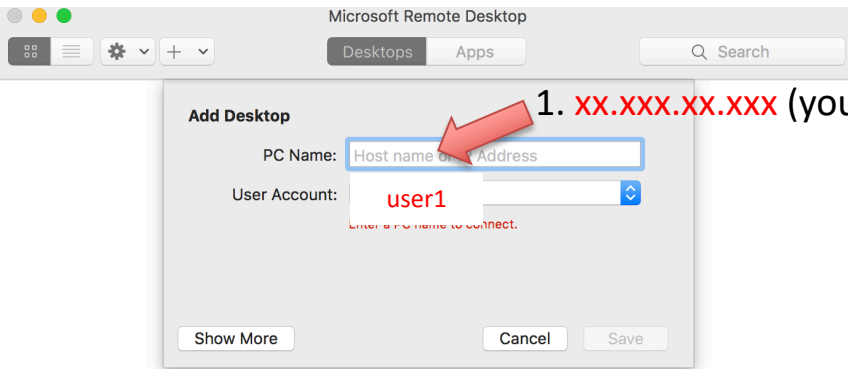
- Macbooks: Microsoft Remote Desktop **10**
(do not use version 8)



Set up your remote desktop (Windows)



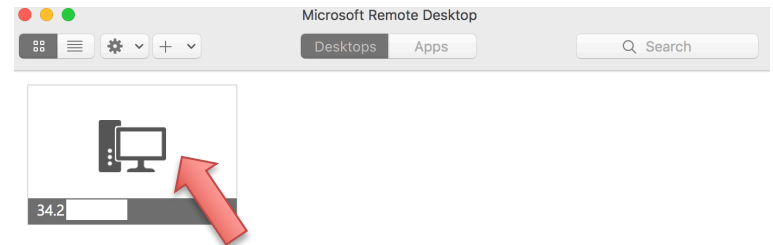
Set up your remote desktop (Mac)



1. **xx.xxx.xx.xxx** (your server's IP address)

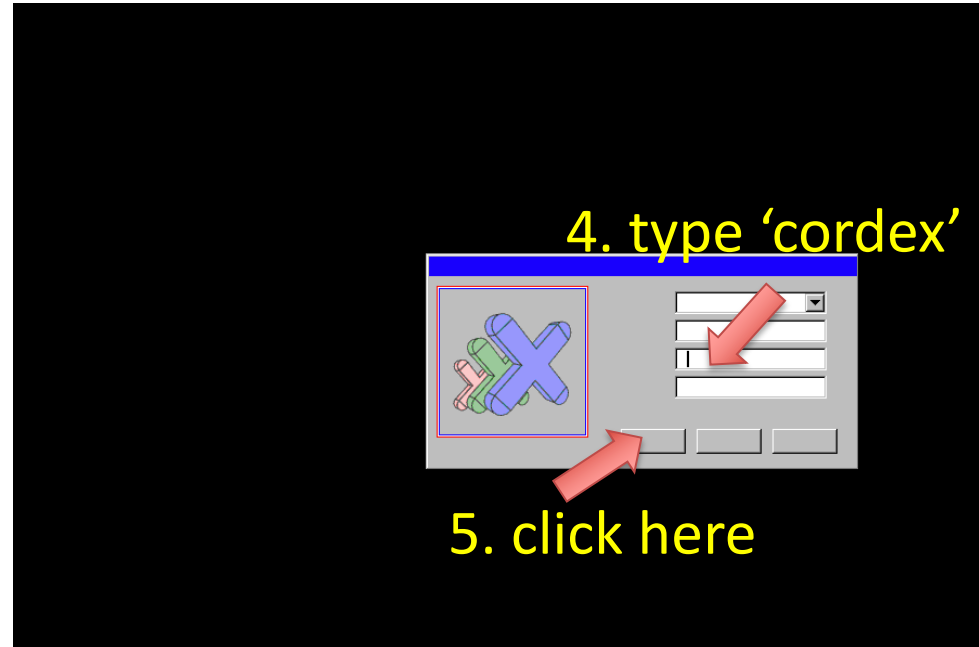
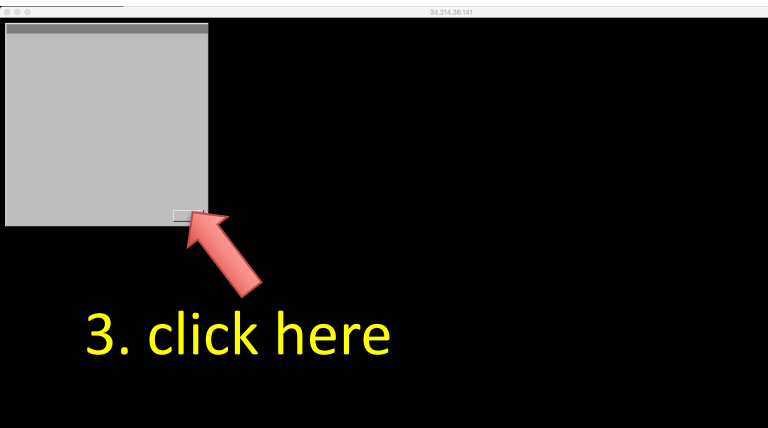
Add your first desktop connection to get started.

Add desktop



2. **Double click!!!**

Bugs in the Mac version



- **Activity #1**
: Correct biases in CORDEX RCM simulations
- Activity #2
: Evaluate CORDEX RCM simulations
- Activity #3
: Pointwise Statistical downscaling using RCMES
- Activity #4
: Download and visualize the NEX-GDDP data

Running the bias correction script

(courtesy of Dr. TJ Vandal at NASA Ames, <https://github.com/tjvandal/bcsd-python>)

1. Open Terminal and type `cd RCMES`

(Five options: please choose one of yaml files)

ex) To correct biases in the CSIRO-MK3-6-0_IITM-RegCM4-4_v5 for the CORDEX South Asia domain,

Python script

One of the five configuration files

```
python CORDEX_TRMM_BC_example.py CORDEX_WAS_CSIRO-QCCCE-CSIRO-Mk3-6-0_IITM-RegCM4-4_v5.yaml
```

(Running this parallelized script takes more than an hour.)

```
{43}: [/home/user1/RCMES] % python CORDEX_TRMM_BC_example.py CORDEX_WAS_CCCma-CanESM2_IITM-RegCM4-4_v5.yaml
/home/ubuntu/anaconda2/lib/python2.7/site-packages/xarray/conventions.py:9: FutureWarning: The pandas.tslib module is deprecated and will be removed in a future version.
  from pandas.tslib import OutOfBoundsDatetime
Case: BC_pr_WAS_CCCma-CanESM2_IITM-RegCM4_rcp85_using_TRMM
loading observations
loading modeled
starting bias correction
Day = 1/365
Running parallel jobs (number of latitudes) 167
execution time to correct biases for one day: 22.0402040482 seconds
Day = 2/365
Running parallel jobs (number of latitudes) 167
execution time to correct biases for one day: 21.3773720264 seconds
Day = 3/365
Running parallel jobs (number of latitudes) 167
execution time to correct biases for one day: 21.0466251373 seconds
Day = 4/365
Running parallel jobs (number of latitudes) 167
execution time to correct biases for one day: 20.7653388977 seconds
Day = 5/365
Running parallel jobs (number of latitudes) 167
execution time to correct biases for one day: 19.4823129177 seconds
Day = 6/365
Running parallel jobs (number of latitudes) 167
execution time to correct biases for one day: 19.6706910133 seconds
Day = 7/365
Running parallel jobs (number of latitudes) 167
execution time to correct biases for one day: 19.6262059212 seconds
Day = 8/365
Running parallel jobs (number of latitudes) 167
execution time to correct biases for one day: 19.5274200439 seconds
Day = 9/365
Running parallel jobs (number of latitudes) 167
```

Bias Correction of CORDEX simulations

- The IITM-RegCM simulations have high spatial resolution (~44 km) relative to CMIP GCMs.
- ~~BCSD~~ => BC : spatial disaggregation (SD) may not be necessary thanks to the resolution of CORDEX simulations.

Quantile mapping to correct simulated precipitation using TRMM observations (1)

- Inside the configuration file (CORDEX_WAS_CCCma-CanESM2_IITM-RegCM4-4_v5.yaml)

fobserved: TRMM_regridded_RegCM4-4_v5_day_19980101-20131201_WAS-44.nc

observed_varname: TRMM_daily_pr

fmodeled_present: pr_WAS-44_CCCma-CanESM2_historical_r1i1p1_IITM-RegCM4-4_v5_day_19900101-20051231.nc

fmodeled_future: pr_WAS-44_CCCma-CanESM2_rcp85_r1i1p1_IITM-RegCM4-4_v5_day_20840101-20991231.nc

modeled_varname: pr

(Observation)

Read TRMM_daily_pr from TRMM_regridded_RegCM4-4_v5_day_19980101-20131201_WAS-44.nc

(Simulation for the present climate)

Read pr from pr_WAS-

44_***_19900101-20051231.nc

(Simulation for the future climate)

Read pr from pr_WAS-

44_***_20840101-20991231.nc

Quantile mapping to correct simulated precipitation using TRMM observations (2)

- At each RCM grid point, biases in simulated precipitation are corrected for each quantile (0.5-99.5%) by comparing two cumulative distributions from TRMM and the RCM (± 15 days).

(Observation)

TRMM_daily_pr for 19980101-20131231

(Simulation for the future climate)

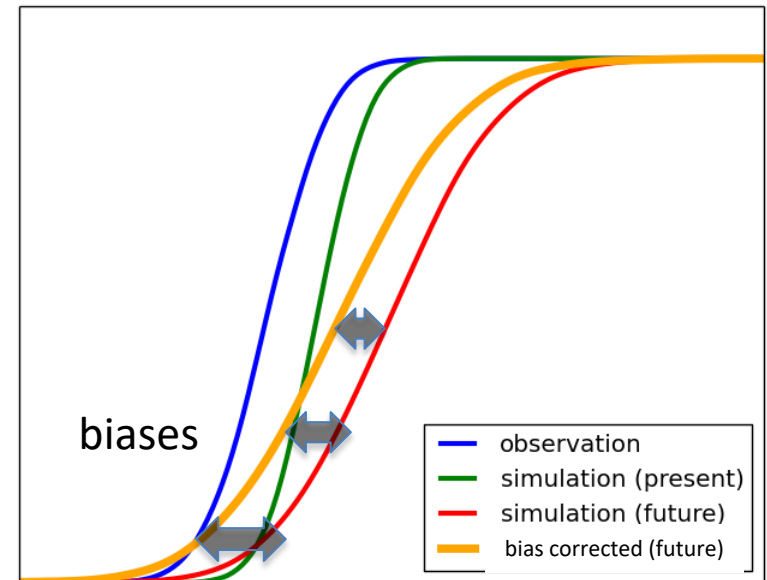
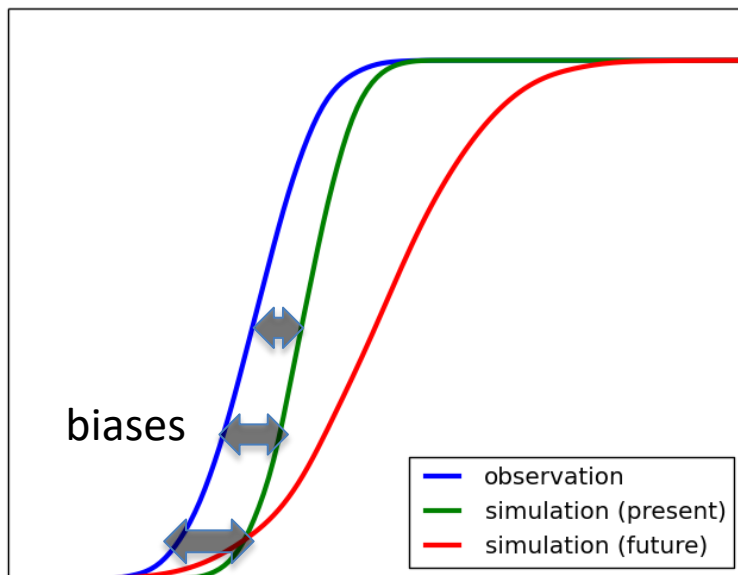
pr_WAS-44_***_20840101-20991231.nc

(Simulation for the present climate)

pr_WAS-44_***_19900101-20051231.nc

(Bias corrected future simulation)

BC_pr_WAS-44_***_20840101-20991231.nc

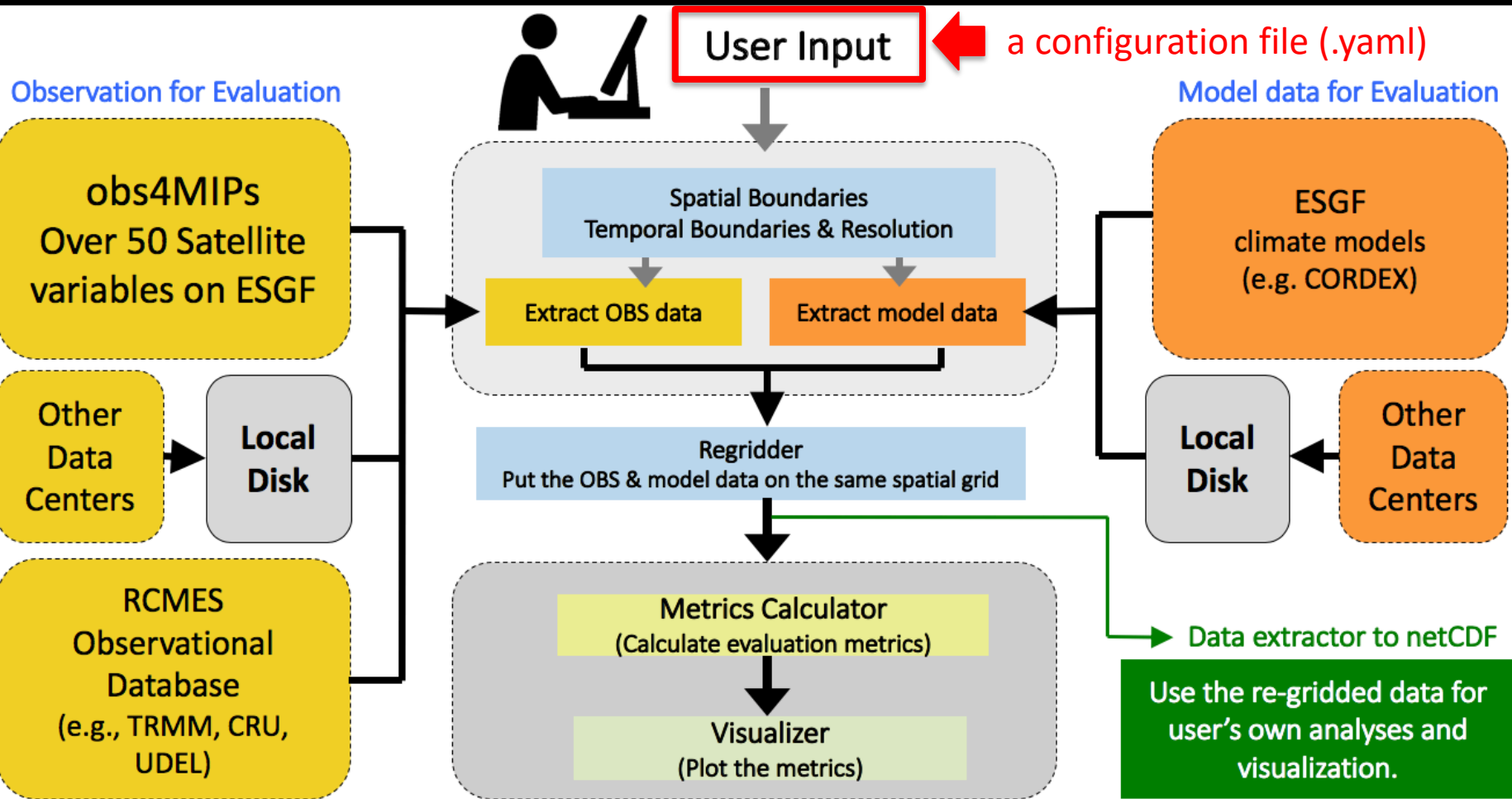


- Activity #1
: Correct biases in CORDEX RCM simulations
- **Activity #2**
: Evaluate CORDEX RCM simulations
- Activity #3
: Pointwise Statistical downscaling using RCMES
- Activity #4
: Download and visualize the NEX-GDDP data

The Regional Climate Model Evaluation System (RCMES, <https://rcmes.jpl.nasa.gov>)

- Lee et al. (2018), Regional Climate Model Evaluation System powered by Apache Open Climate Workbench v1.3.0: an enabling tool for facilitating regional climate studies, Geoscientific Model Development.
- Python-based open source software powered by the Apache Open Climate Workbench (OCW)
- Main components
 - 1) Database of observations
 - 2) Toolkit for facilitating systematic evaluation of CORDEX RCMs using satellite observations (Activity #2)
 - 3) Statistical downscaling of coarse-resolution GCM output or bias correction of high-resolution RCM output (Activity #1 & 3)
 - 4) Stand-alone scripts for data processing and visualization based on OCW

Model evaluation using RCMES



Apache Open Climate Workbench (OCW)

<https://climate.apache.org/>

Apache Open Climate Workbench

Downloads

Development ▾

Documentation ▾

Community ▾

ASF ▾



Apache Open Climate Workbench

Apache Open Climate Workbench is an effort to develop software that performs climate model evaluation using model outputs from a variety of different sources the [Earth System Grid Federation](#), the [Coordinated Regional Climate Downscaling Experiment](#), the [U.S. National Climate Assessment](#) and the [North American Regional Climate Change Assessment Program](#) and temporal/spatial scales with remote sensing data from [NASA](#), [NOAA](#) and other agencies. The toolkit includes capabilities for rebinning, metrics computation and visualization.

Apache Open Climate Workbench 1.0.0 Released

September 24, 2015

The Apache Open Climate Workbench team is pleased to announce the 1.0.0 release! This release addresses no less than 52 issues, bugs, and improvements. For a full breakdown of the work packaged into this release please see the [release report](#).


Some important features this release packs include statistical downscaling capabilities such as Delta Method, Quantile Mapping and Quantile Regression, configuration driven evaluation improvements, better plot support to config based evaluations and a brand new module to calculate area mean and standard deviation with given subregion information.

Download




We urge all users to upgrade to this version immediately. Please let us know how you are using OCW over on the [community mailing lists](#).

Finally, please see our [1.1 Roadmap](#) for an idea of the next line of development.

Source at github.com/apache/climate

 This repository Search

Pull requestsIssuesGist

apache / climate

mirrored from [git://git.apache.org/climate.git](https://git.apache.org/climate.git)

Watch 8Star 17Fork 36

[Code](#) [Pull requests 4](#) [Pulse](#) [Graphs](#)

Mirror of Apache Open Climate Workbench

1,791 commits16 branches7 releases13 contributors

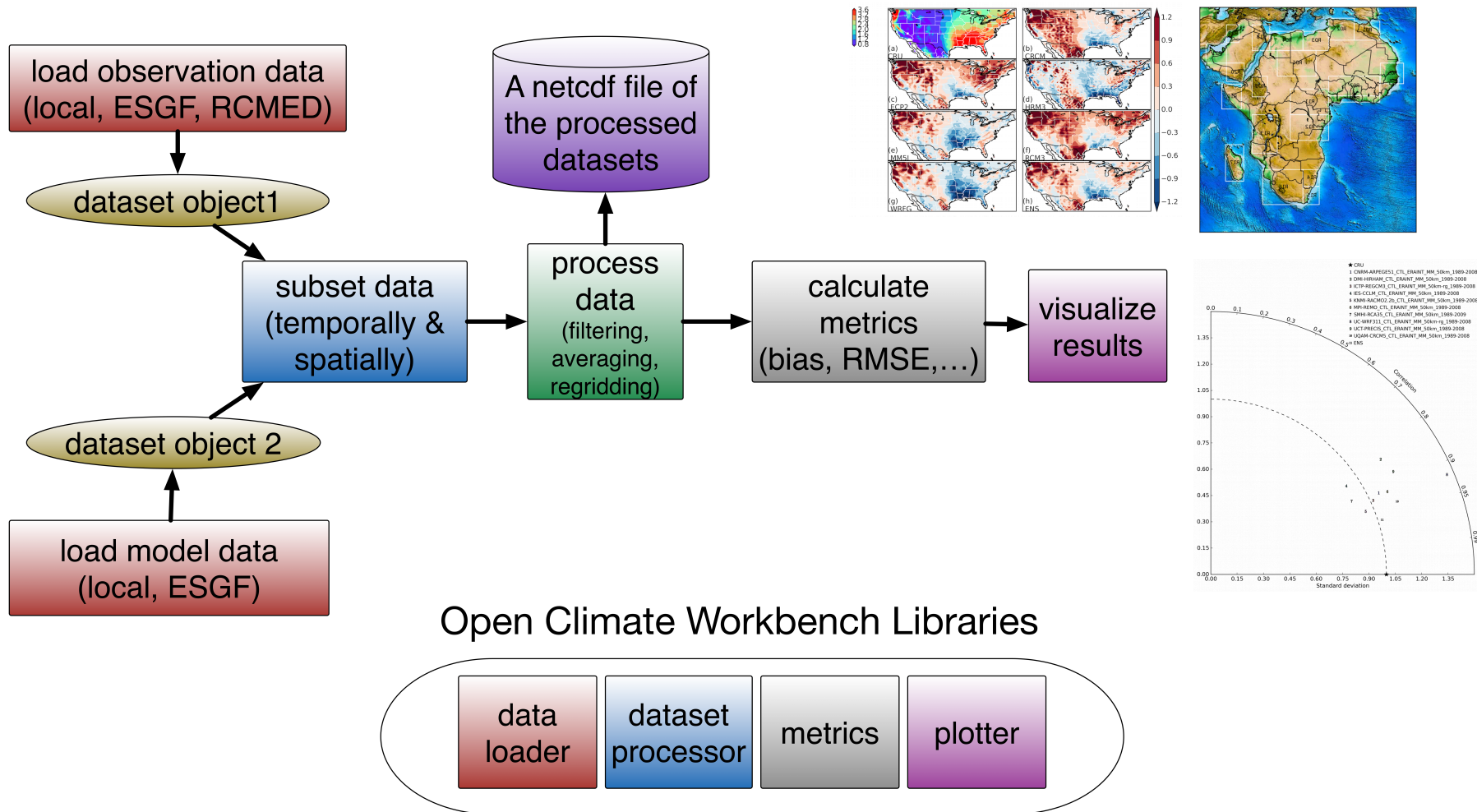
Branch: master New pull request

New fileUpload filesFind fileHTTPS https://github.com/apache, Download ZIP

huikyole CLIMATE-771 - Critical bugs in LAT_NAMES and LON_NAMES in local.py Latest commit fd6debb 10 days ago

RCMES	CLIMATE-770 - Make boundary checking optional in spatial_regrid	12 days ago
docs	[RELEASE PREPARE] Prep for 1.0.0 release candidate	6 months ago
easy-ocw	Resolve CLIMATE-560 : Does not assume installation directory within e...	3 months ago
examples	Examples that use dataset_processor.temporal_rebin have been updated	a month ago
mccsearch	Resolve CLIMATE-559. Merge PR #142.	a year ago
obs4MIPs	Add Resources sheet into excel spreadsheet. It is no longer necessary...	2 years ago
ocw-ui	CLIMATE-572 Address deprecation and WARN's in ocw-ui/frontend npm ins...	12 days ago
ocw-vm	CLIMATE-712 - Update VM build to use conda install	4 months ago
ocw	Merge branch 'master' of https://github.com/apache/climate into CLIMA...	10 days ago
ocw_config_runner	adding init python file	6 months ago
.gitignore	Update gitignore so setup.py develop artifacts are ignored	a year ago
.mailmap	CLIMATE-608 - Add mailmap file to repo	a year ago
.pylintrc	CLIMATE-600 - Add basic .pylintrc with some sane defaults	a year ago
CHANGES.txt	[RELEASE PREPARE] Prep for 1.0.0 release candidate	6 months ago
KEYS	[RELEASE PREPARE] Prep for 1.0.0 release candidate	6 months ago
LICENSE.txt	add README to provide information on how to retrieve TRMM data from G...	2 years ago
MANIFEST.in	CLIMATE-725 Ensure that OCW 1.1 Test PyPi Works as Expected	2 months ago
NOTICE.txt	CLIMATE-342 - Update NOTICE with public domain note for TaylorDiagram	2 years ago
README.md	CLIMATE-684 - Add link to Python API to README	6 months ago

Running RCMES using configuration files: a complete start-to-finish workflow to evaluate multi-scale climate models using observational data



Running the systematic evaluation of CORDEX WAS simulations

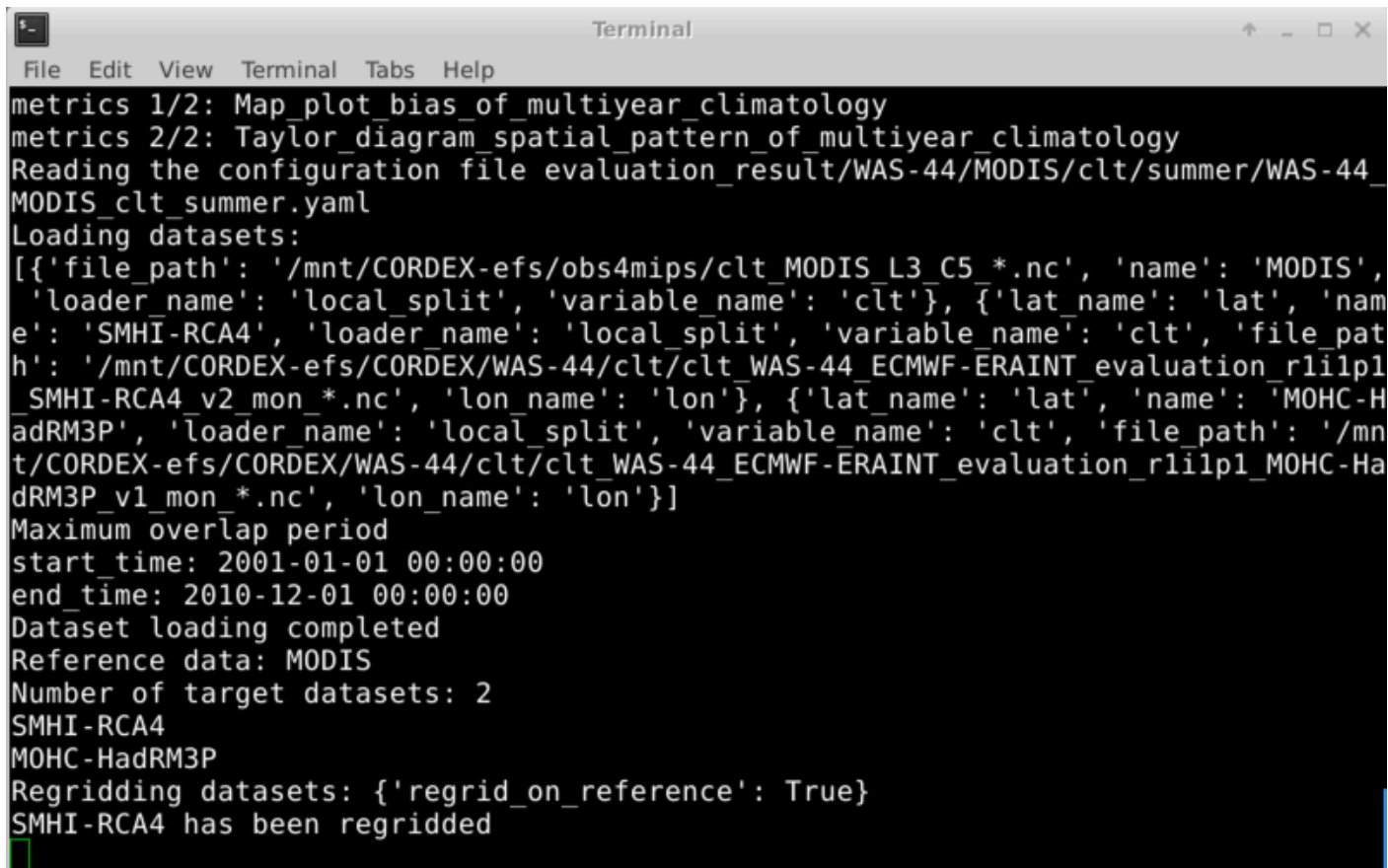
1. Open Terminal and type

```
cd RCMES
```

```
cd CORDEX_evaluation
```

2. Type

```
./evaluate_WAS-44
```



```
Terminal
File Edit View Terminal Tabs Help
metrics 1/2: Map_plot_bias_of_multiyear_climatology
metrics 2/2: Taylor_diagram_spatial_pattern_of_multiyear_climatology
Reading the configuration file evaluation_result/WAS-44/MODIS/clt/summer/WAS-44_
MODIS_clt_summer.yaml
Loading datasets:
[{'file_path': '/mnt/CORDEX-efs/obs4mips/clt_MODIS_L3_C5 *.nc', 'name': 'MODIS',
  'loader_name': 'local_split', 'variable_name': 'clt'}, {'lat_name': 'lat', 'name': 'SMHI-RCA4', 'loader_name': 'local_split', 'variable_name': 'clt', 'file_path': '/mnt/CORDEX-efs/CORDEX/WAS-44/clt/clt_WAS-44_ECMWF-ERAINT_evaluation_r1ilp1_SMHI-RCA4_v2_mon *.nc', 'lon_name': 'lon'}, {'lat_name': 'lat', 'name': 'MOHC-HadRM3P', 'loader_name': 'local_split', 'variable_name': 'clt', 'file_path': '/mnt/CORDEX-efs/CORDEX/WAS-44/clt/clt_WAS-44_ECMWF-ERAINT_evaluation_r1ilp1_MOHC-HadRM3P_v1_mon *.nc', 'lon_name': 'lon'}]
Maximum overlap period
start_time: 2001-01-01 00:00:00
end_time: 2010-12-01 00:00:00
Dataset loading completed
Reference data: MODIS
Number of target datasets: 2
SMHI-RCA4
MOHC-HadRM3P
Regridding datasets: {'regrid_on_reference': True}
SMHI-RCA4 has been regridded
```

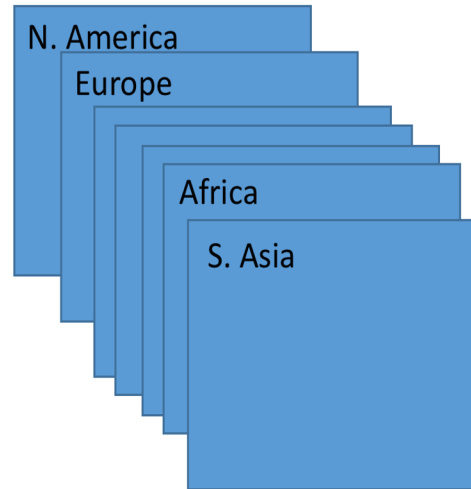

ERA-Interim Reanalysis Forced RCM simulations Available on ESGF



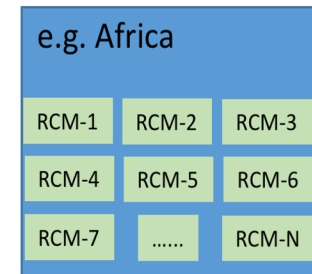
Schematic of Multi-Domain, Multi-Model and Multi-Variate
CORDEX Model Evaluation with Obs4MIPs

Schematic of Multi-Domain, Multi-Model and Multi-Variate
CORDEX Model Evaluation with Obs4MIPs

CORDEX has 14 Domains



Each Domain has N RCMS

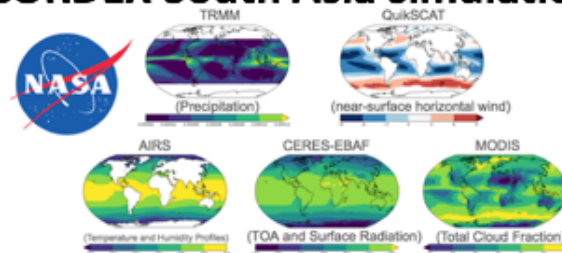
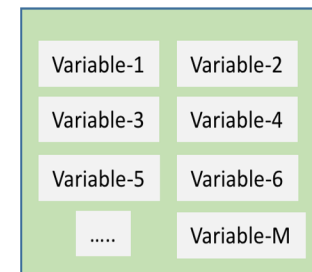


**Mount an EFS storage to
an AWS EC2 instance**

**Elastic File System (EFS) storage
containing obs4MIPs and
CORDEX South Asia simulations**

Model Evaluation

Each RCM has M Variables



```

workdir: /home/goodman/data_processing/CORDEX/analysis/NAM-44/CERES-EBAF/rlus/annual
output_netcdf_filename: rlus_CERES-EBAF_NAM-44_annual.nc

# (RCMES will temporally subset data between month_start and month_end.
# If average_each_year is True (False), seasonal mean in each year is (not) calculated and used for metrics calcul
time:
  maximum_overlap_period: True
  temporal_resolution: monthly
  month_start: 1
  month_end: 12
  average_each_year: True

space:
  boundary_type: CORDEX NAM

regrid:
  regrid_on_reference: True

datasets:
- loader_name: local_split
  name: CERES-EBAF
  file_path: /proj3/data/obs4mips/rlus_CERES-EBAF_L3B_Ed2-8_*.nc
  variable_name: rlus
- loader_name: local_split
  name: UQAM-CRCM5
  file_path: /proj3/data/CORDEX/NAM-44/rlus/rlus_NAM-44_ECMWF-ERAINT_evaluation_r1i1p1_UQAM-CRCM5_v1_mon_*.nc
  variable_name: rlus
  lat_name: lat
  lon_name: lon
- loader_name: local_split
  name: SMHI-RCA4
  file_path: /proj3/data/CORDEX/NAM-44/rlus/rlus_NAM-44_ECMWF-ERAINT_evaluation_r1i1p1_SMHI-RCA4_v1_mon_*.nc
  variable_name: rlus
  lat_name: lat
  lon_name: lon
- loader_name: local_split
  name: DMI-HIRHAM5
  file_path: /proj3/data/CORDEX/NAM-44/rlus/rlus_NAM-44_ECMWF-ERAINT_evaluation_r1i1p1_DMI-HIRHAM5_v1_mon_*.nc
  variable_name: rlus
  lat_name: lat
  lon_name: lon
- loader_name: local_split
  name: MOHC-HadRM3P
  file_path: /proj3/data/CORDEX/NAM-44/rlus/rlus_NAM-44_ECMWF-ERAINT_evaluation_r1i1p1_MOHC-HadRM3P_v1_mon_*.nc
  variable_name: rlus
  lat_name: lat
  lon_name: lon

```

Season

Domain

Observations

Models

Why we need “Systematic Evaluation”

- This Config file (namelist file) is necessary to run each evaluation combination (CORDEX Domain, Season and Variable), forming a large “evaluation matrix”.
- 14 variables x 13 domains x 3 seasons x ~10 models > 5000 evaluations
- Writing that many Config files manually would be cumbersome/prohibitive.

Solution: Extract metadata from input filenames

rlus_NAM-44_ECMWF-ERAINT_evaluation_r1i1p1_UQAM-CRCM5_v1_mon_*.nc

Variable Domain

Model

User Input:
Dataset Locations
(obs4mips, CORDEX)

Evaluation Groups
(Season, Domain,
Variable)

Config File

RCMES

We can group all models and obs datasets together by common attributes (domain and variable) to form a unique evaluation, and therefore **automatically generate Config Files using only the dataset locations as user input.**

```
./evaluate_WAS-44
```

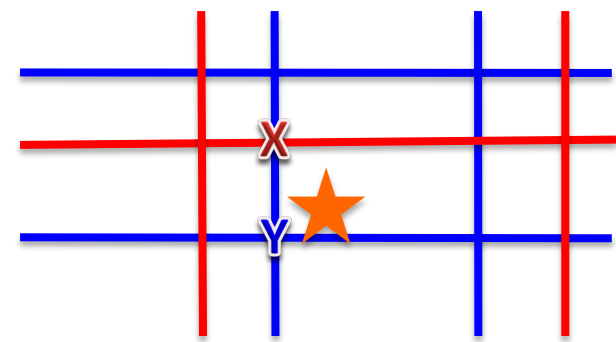


output folder name

```
python cordex.py WAS-44 evaluation_result /mnt/CORDEX-  
efs/obs4mips /mnt/CORDEX-efs/CORDEX/WAS-44
```

- Activity #1
: Correct biases in CORDEX RCM simulations
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Statistical downscaling using RCMES



- To statistically downscale CMIP5 variables at a specific location (star marker), RCMES uses statistical relationship between the nearest model grid point data (X) and observation grid point data (Y)

: simultaneous correction of both bias and collocation

$$Y = f(X)$$

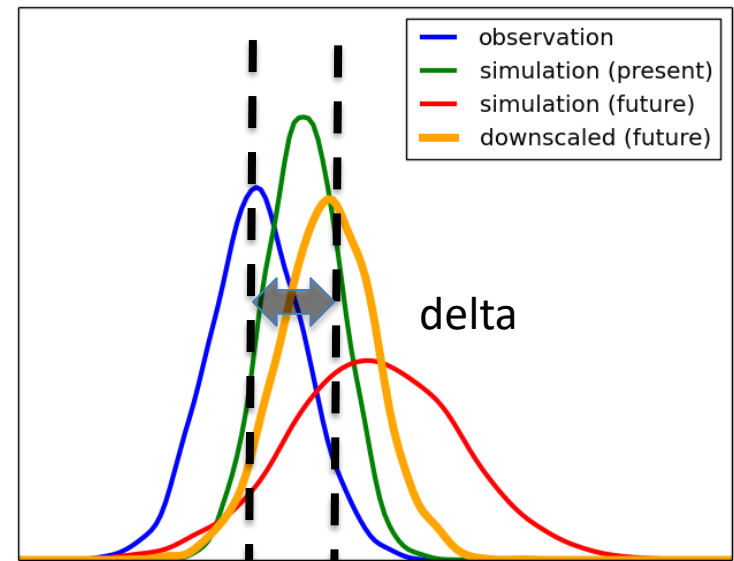
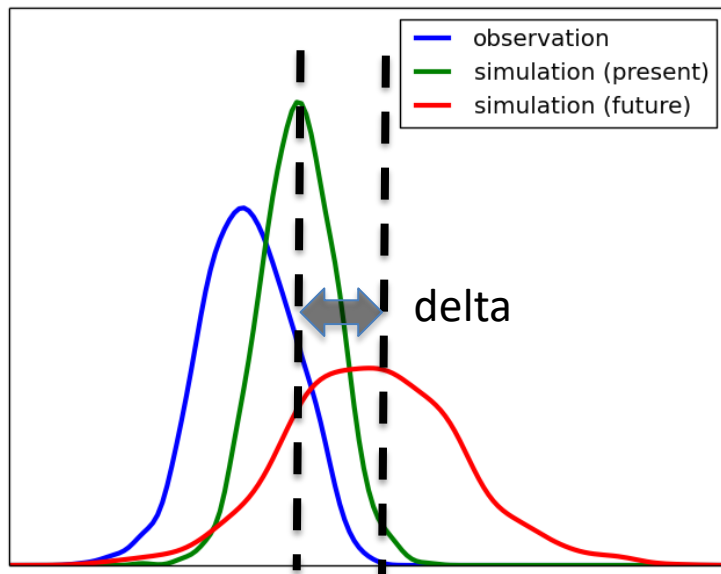
- Four different methods for model calibration (Stoner et al., 2013)
 - Delta method (addition)
 - Delta method (bias correction)
 - Quantile mapping
 - Asynchronous linear regression
- The observational datasets in RCMES database can be used to determine the observation-model relationship.

Delta method (Delta addition)

Y_0 : present observation, X_0 : present simulation, X_1 : future simulation

$$Y_1 = Y_0 + \bar{X}_1 - \bar{X}_0$$

- (future climate) = (present observation) + (mean difference between X_0 and X_1)

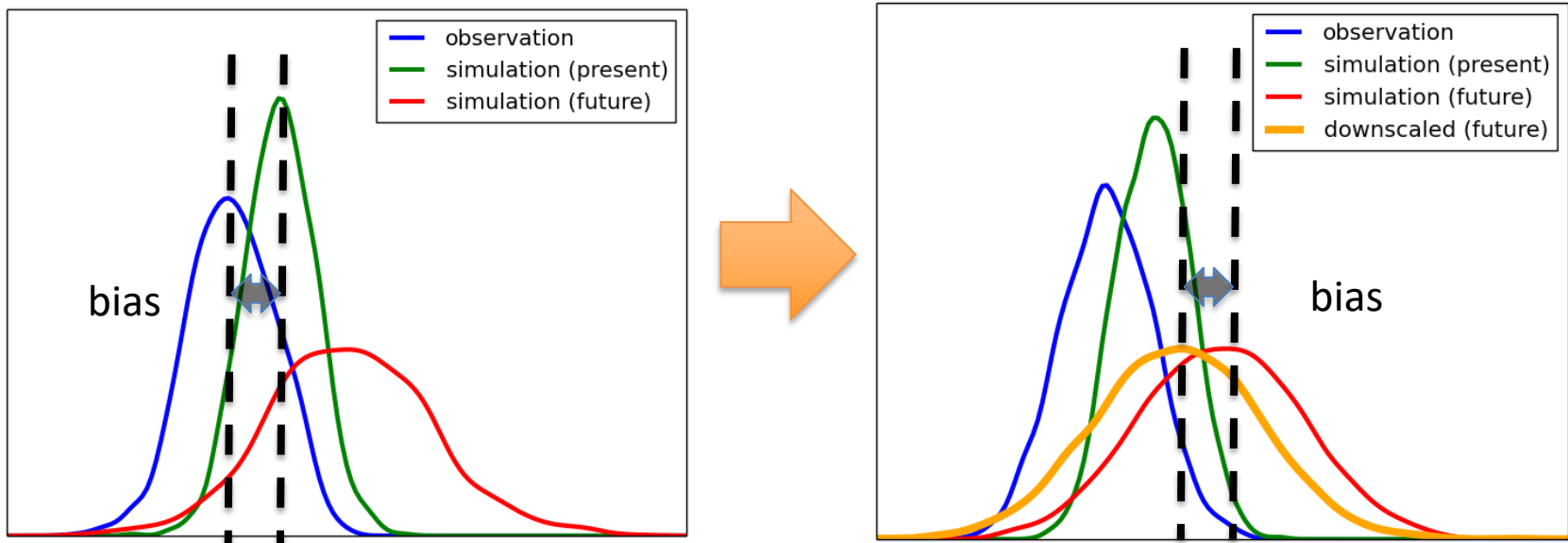


Delta method (Bias correction)

Y_0 : present observation, X_0 : present simulation, X_1 : future simulation

$$Y_1 = X_1 + \bar{Y}_0 - \bar{X}_0$$

- (future climate) = (future simulation) + (mean bias)

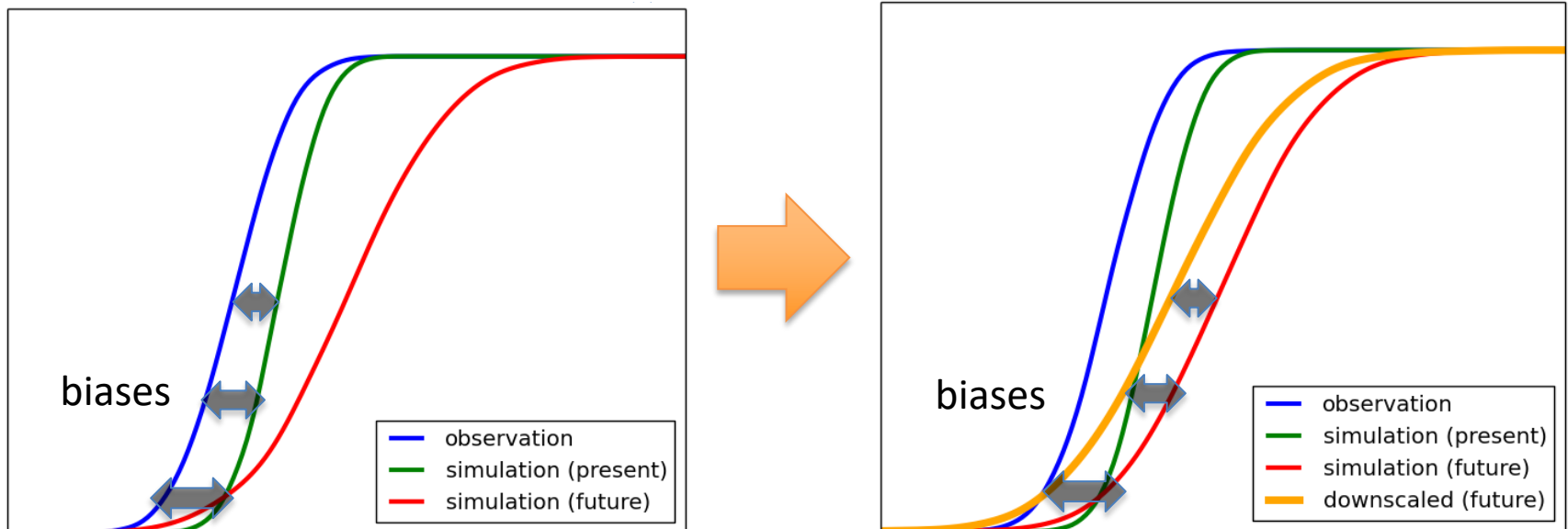


Quantile mapping

Y_0 : present observation, X_0 : present simulation, X_1 : future simulation

$Y_1 = f(X_1)$ where f is bias correction function for each quantile ($Y_0 = f(X_0)$).

- (future climate) = (bias corrected future simulation)
- Bias is corrected for each quantile.



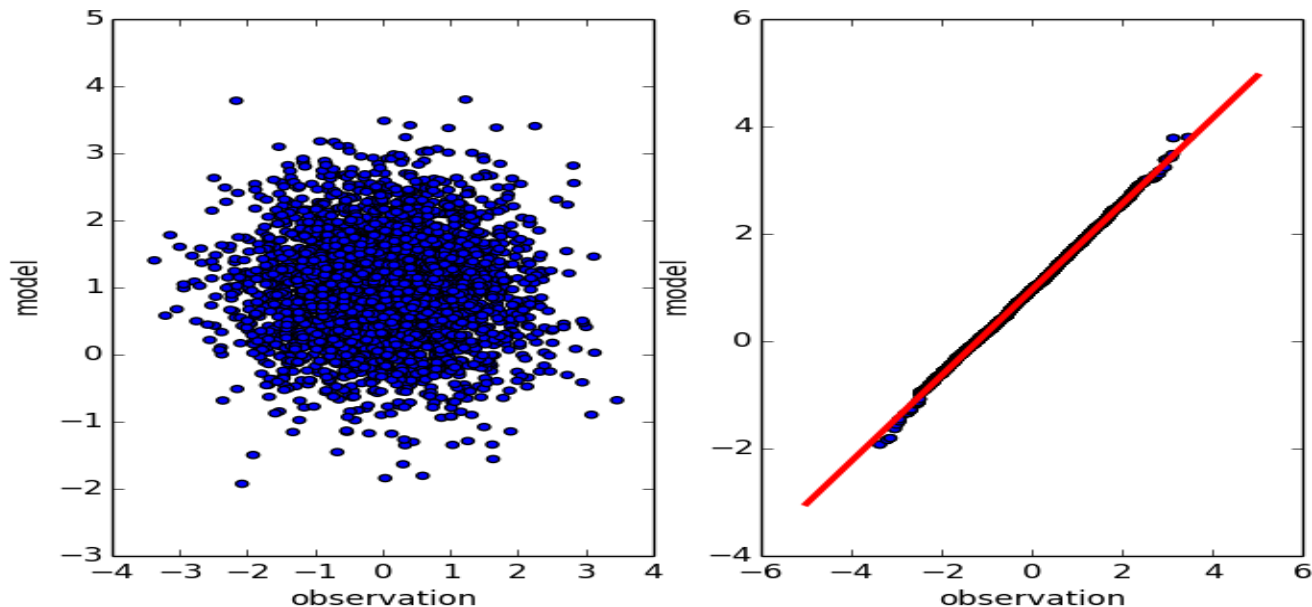
Asynchronous linear regression

Y_0 : present observation, X_0 : present simulation, X_1 : future simulation

Y'_0, X'_0, X'_1 : sorted in ascending order

$Y'_1 = aX'_1 + b$ where $Y'_0 = aX'_0 + b$. a and b are the slope and intercept for the least square regression line.

- The linear relationship between observation and present simulation is determined after sorting them in ascending order.



Statistical Downscaling using RCMES

1. Open Terminal and `cd RCMES/statistical_downscaling/`

2. To run the statistical downscaling script, type

`python run_statistical_downscaling.py MPI_tasmin_DJF.yaml`

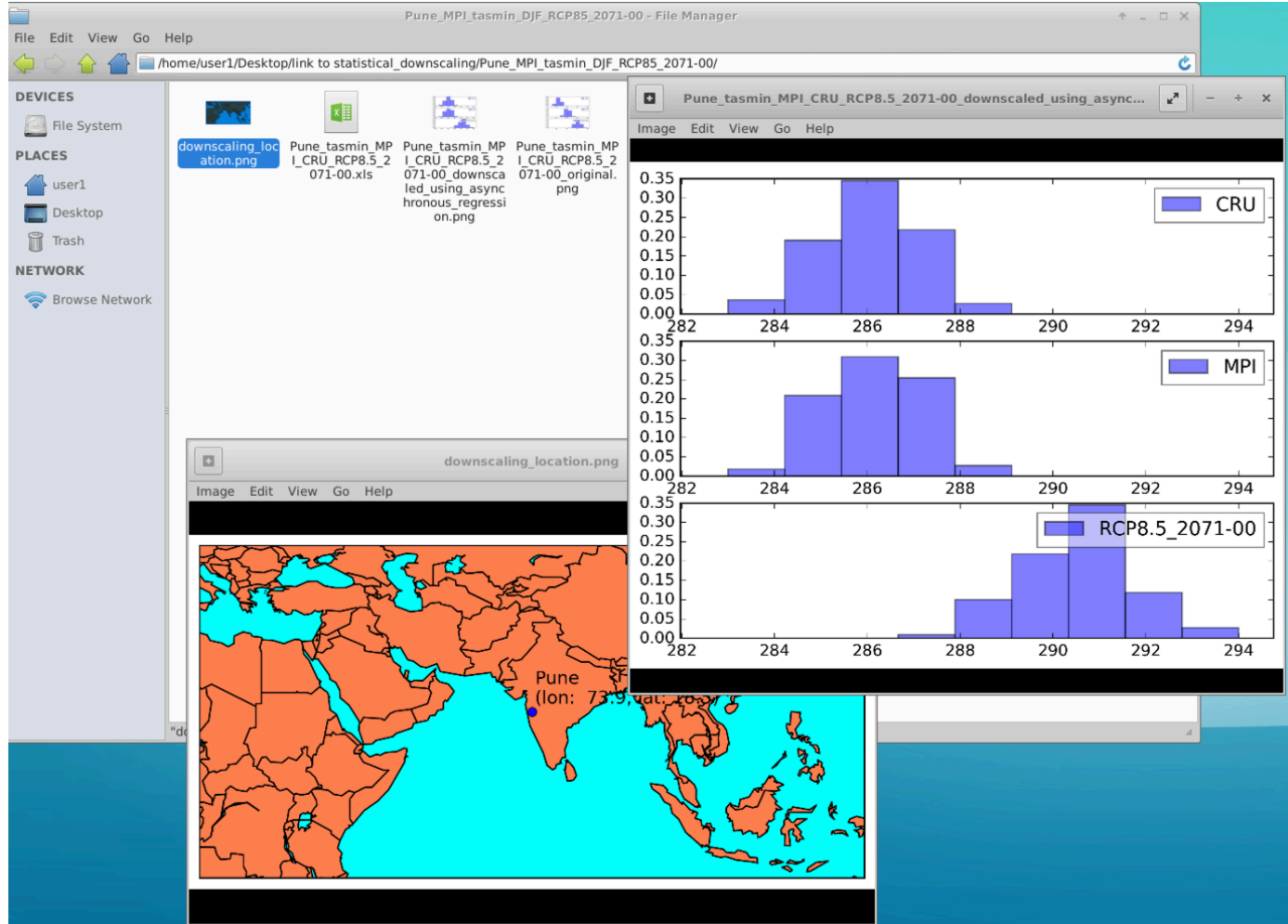
Python script

Configuration file

```
{13} [/home/ubuntu] % cd RCMES/statistical_downscaling/  
data/ LaPaz_MPI_tas_JJA_RCP85_2071-00/ MIROC5_tasmax_JJA.yaml MPI_tas_JJA.yaml run_statistical_downscaling.py  
{14} [/home/ubuntu/RCMES/statistical_downscaling] % python run_statistical_downscaling.py MPI_tas_JJA.yaml  
Reading the configuration file MPI_tas_JJA.yaml  
Processing CRU data  
Loading ./data/tas_cru_monthly_1981-2010.nc into an OCW Dataset Object  
CRU values shape: (times, lats, lons) - (360, 360, 720)  
  
Loading ./data/tas_Amon_MPI_decadal1980_198101-201012.nc into an OCW Dataset Object  
MPI values shape: (times, lats, lons) - (360, 96, 192)  
  
RCP8.5_2071-00:MPI values shape: (times, lats, lons) - (360, 96, 192)  
  
Temporal subsetting for the selected month(s)  
Spatial aggregation of observational data near latitude 10.75 and longitude 106.67  
Creating a statistical downscaling object  
asynchronous_regression: Downscaling model output  
Plotting results  
Generating spreadsheet  
{15} [/home/ubuntu/RCMES/statistical_downscaling] %
```

View the statistically downscaled tasmin results

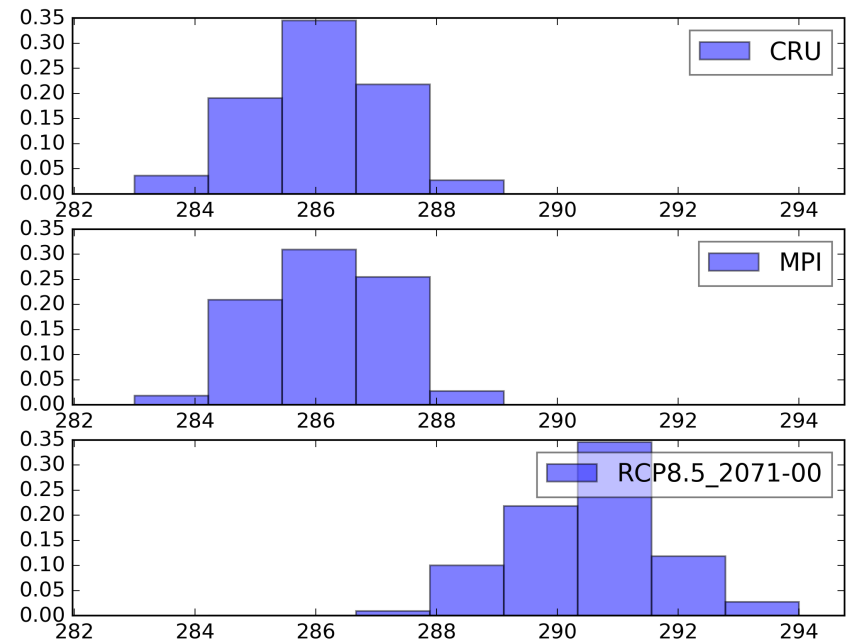
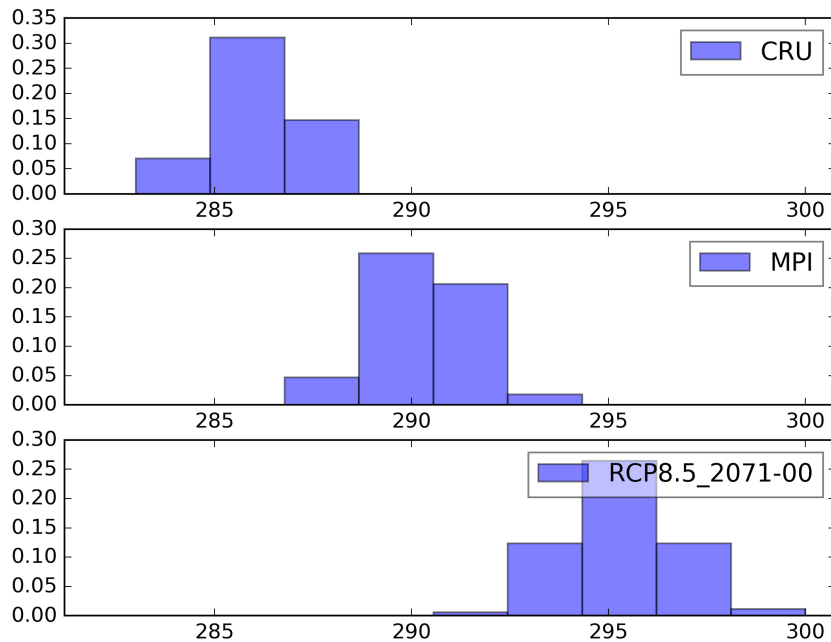
- The results can be found in statistical_downscaling/Pune_tasmin_MPI_CRU_RCP8.5_2071-00 folder



Quantile mapping of the daily minimum temperature for Pune in DJF

Original model output

Statistically downscaled model output



Run another example: taxmax in Pune

```
python run_statistical_downscaling.py MIROC5_taxmax_DEC.yaml
```

Python script

Configuration file

Make your own example by editing the yaml file

case_name: Pune_MIROC5_tasmax_DEC_RCP85_2071-00

Output folder name

downscaling_option: 3

location:

name: Pune

grid_lat: 18.5204

Search Google with the keyword 'latitude and longitude of XXX'

grid_lon: 73.8567

month_index: !!python/tuple [12]

Season: December only in this case

reference:

data_source: local

data_name: CRUs

path: ./data/tasmax_cru_monthly_1981-2010.nc

variable: tasmax

model:

data_name: MIROC5

variable: tasmax

present:

path: ./data/tasmax_Amon_MIROC5_decadal1980_198

future:

scenario_name: RCP8.5_2071-00

path: ./data/tasmax_Amon_MIROC5_rcp85_207101-210012.nc

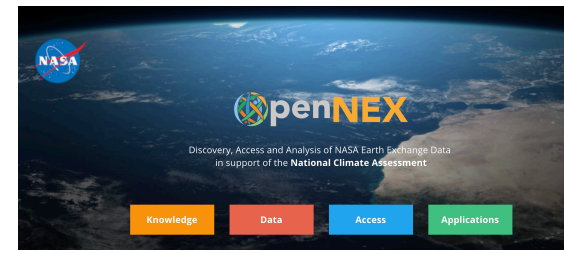
(Options)

1. **IPSL, MPI, and MIROC5**
2. **tas, tasmin, and tasmax**
3. **RCP 4.5 and 8.5**
4. **(2041-2070) and (2071-2100)**

- Activity #1
 - : Correct biases in CORDEX RCM simulations
- Activity #2
 - : Pointwise Statistical downscaling using RCMES
- **Activity #3**
 - : **Download and visualize the NEX-GDDP data**
- Activity #4
 - : Analyze the bias corrected RCM output

NASA's Earth Exchange

(NEX, <https://nex.nasa.gov>)



- NEX is a platform for scientific collaboration, knowledge sharing and research for the Earth science community.
- The new project, Open NEX, is aimed at making a number of important datasets more accessible.

NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP)

CMIP5 historical and RCP
4.5/8.5 simulations
(from 21 models, 1950-2100)

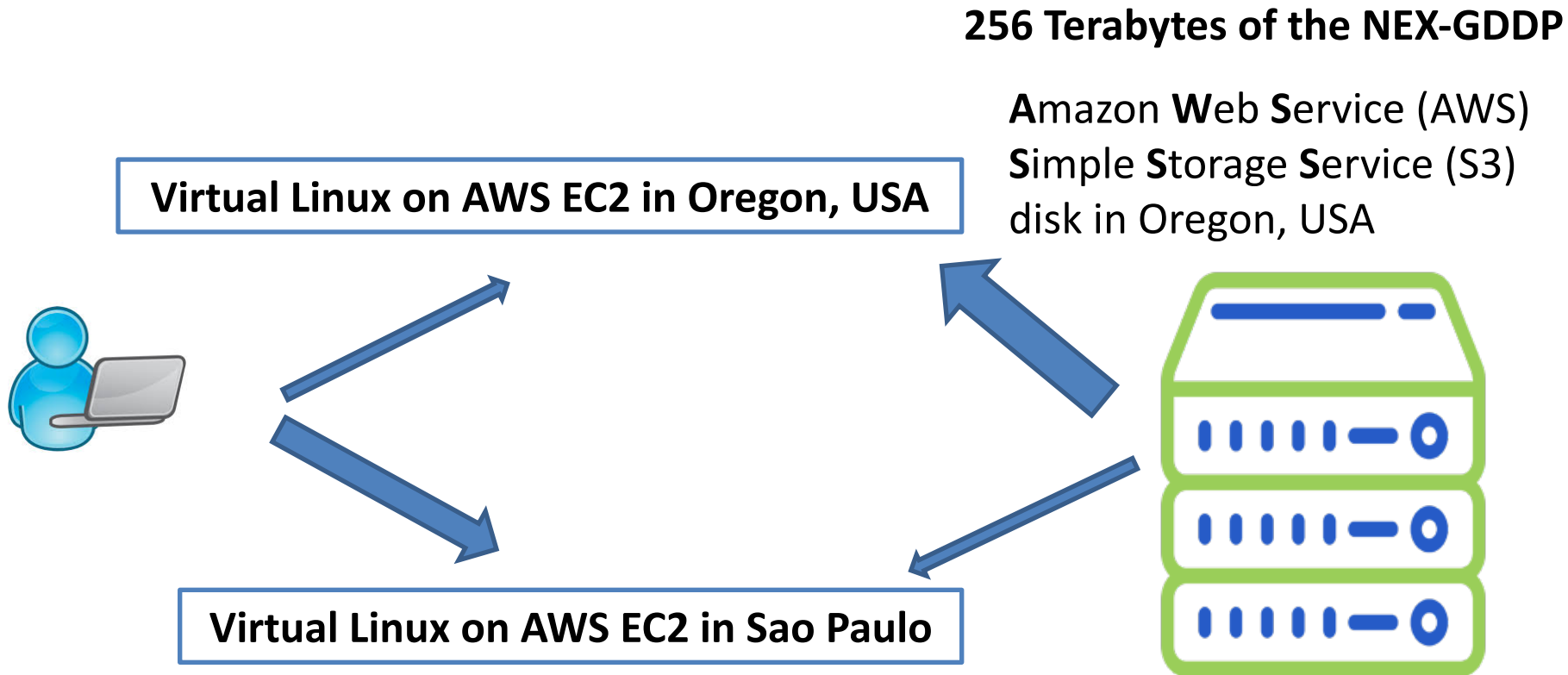
Bias-Correction Spatial
Disaggregation (BCSD)



Global Meteorological
Forcing Dataset
(observation, 1950-2005)

NEX-GDDP
: tasmax, tasmin, precipitation

Access to the statistically downscaled NEX-GDDP



- The NEX S3 is mounted in your linux EC2.
- Open terminal and type `df -h`

What are inside s3://nasanex?

[/home/ubuntu] %

```
aws s3 ls s3://nasanex
```

PRE AVHRR/

PRE CMIP5/

PRE LOCA/

PRE Landsat/

PRE MAIAC/

PRE MODIS/

PRE NAIP/

PRE NEX-DCP30/

PRE NEX-GDDP/

List, download and visualize NEX-GDDP

1. Open terminal and `cd NEX-GDDP`

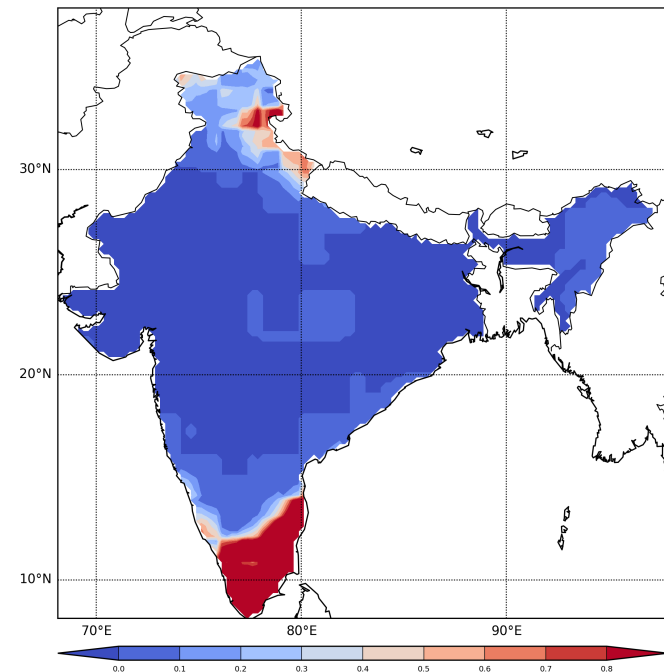
2. `./list`

3. `./download` **How fast!**

This script is an example of **Open Climate Workbench**, an open-source Python library that comprise **RCMES**.

4. `python plot_NEX-GDDP_example.py`

Statistically downscaled
precipitation from NorESM1-M
model for December 2100



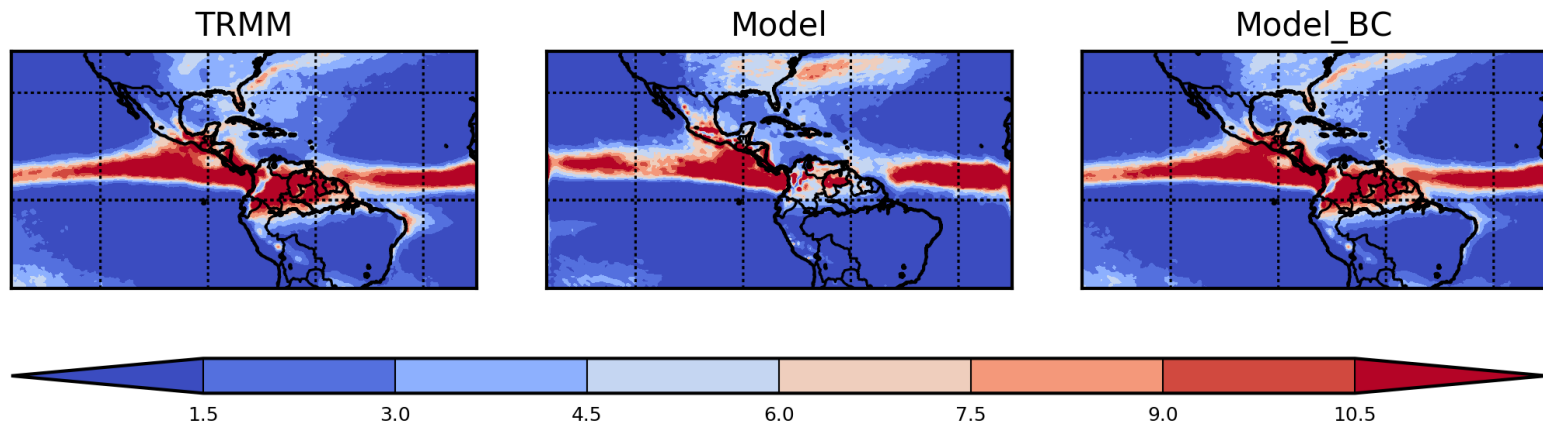
- Activity #1
: Correct biases in CORDEX RCM simulations
- Activity #2
: Pointwise Statistical downscaling using RCMES
- Activity #3
: Download and visualize the NEX-GDDP data
- **Activity #4**
: Analyze the bias corrected RCM output from Activity #1

- Activity #1
: Correct biases in CORDEX RCM simulations
- Activity #2
: Pointwise Statistical downscaling using RCMES
- Activity #3
: Download and visualize the NEX-GDDP data
- **Activity #4**
: **Analyze the bias corrected RCM output**

Compare TRMM, original simulation, and bias corrected simulation

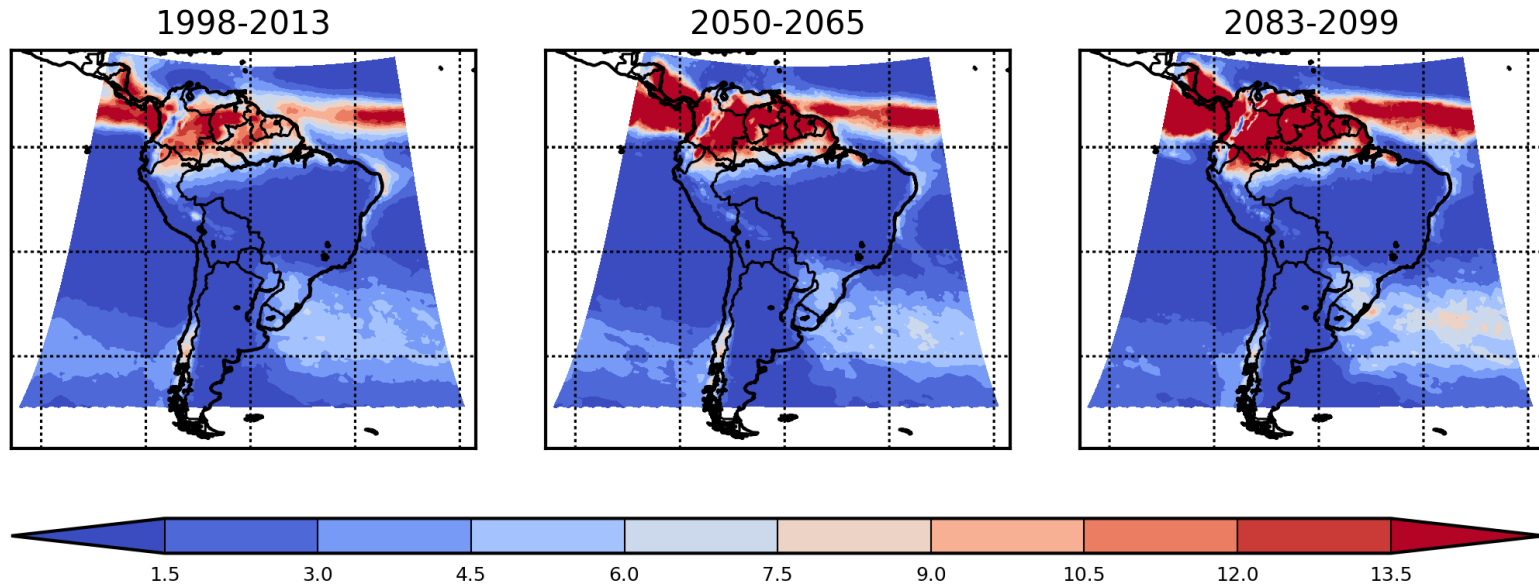
1. Open terminal and `cd RCMES/analysis_examples`

2. `python check_bias_correction.py` ← OCW-based script



How does the bias-corrected precipitation look like in the future
(in July-August, TRMM (1998-2013) vs. two bias-corrected
simulations (2084-2099))?

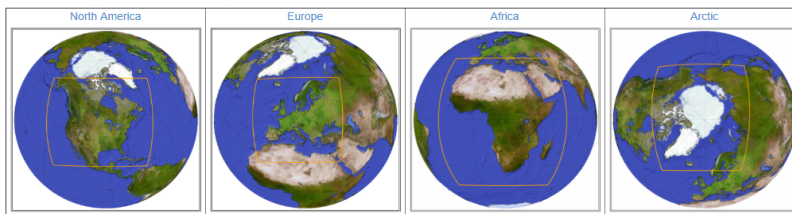
```
python compare_present_and_future.py
```



Future Direction

- Development is ongoing...
 - Adding more metrics to assure traceability and reproducibility of model evaluation results.
 - Growing user and developer base by utilizing AWS and OpenNEX datasets.
- Develop a comprehensive model evaluation system for the United States National Climate Assessment and CORDEX.

Quick Navigation - Jump to Evaluations



Results

North America Evaluations

Reference Dataset	Variables	Results Page by Seasons		
CERES-EBAF	Downwelling Longwave Radiation (Surface)	Annual	Summer	Winter
	Upwelling Longwave Radiation (Surface)	Annual	Summer	Winter
	Upwelling Longwave Radiation (TOA)	Annual	Summer	Winter
	Downwelling Shortwave Radiation (Surface)	Annual	Summer	Winter
	Downwelling Shortwave Radiation (TOA)	Annual	Summer	Winter
	Upwelling Shortwave Radiation (Surface)	Annual	Summer	Winter
	Upwelling Shortwave Radiation (TOA)	Annual	Summer	Winter
		Annual	Summer	Winter

<https://rcmes.jpl.nasa.gov/content/cordex-evaluation>

Where to find more information:

- <http://rcmes.jpl.nasa.gov>
- <http://climate.apache.org/>
- Email team members or dev@climate.apache.org
- <https://nex.nasa.gov>

Contact

Kyo Lee: huikyo.lee@jpl.nasa.gov

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Regional Climate Model Evaluation System powered by Apache Open Climate Workbench v1.3.0: an enabling tool for facilitating regional climate studies

Huikyo Lee¹, Alexander Goodman¹, Lewis McGibbney¹, Duane E. Waliser¹, Jinwon Kim^{2,3}, Paul C. Loikith⁴, Peter B. Gibson¹, and Elias C. Massoud¹

¹Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA

²Joint Institute for Regional Earth System Science & Engineering, University of California, Los Angeles, CA, USA

³National Institute of Meteorological Sciences/Korean Meteorological Administration, Seogwipo, South Korea

⁴Department of Geography, Portland State University, Portland, OR, USA

Correspondence: Huikyo Lee (huikyo.lee@jpl.nasa.gov)

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Abstract. The Regional Climate Model Evaluation System (RCMES) is an enabling tool of the National Aeronautics and Space Administration to support the United States National Climate Assessment. As a comprehensive system for evaluating climate models on regional and continental scales using observational datasets from a variety of sources, RCMES is designed to yield information on the performance of climate models and guide their improvement. Here, we present a user-oriented document describing the latest version of RCMES, its development process, and future plans for improvements. The main objective of RCMES is to facilitate the climate model evaluation process at regional scales. RCMES provides a framework for performing systematic evaluations of climate simulations, such as those from the Coordinated Regional Climate Downscaling Experiment (CORDEX), using in situ observations, as well as satellite and reanalysis data products. The main components of RCMES are (1) a database of observations widely used for climate model evaluation, (2) various data loaders to import climate models and observations on local file systems and Earth System Grid Federation (ESGF) nodes, (3) a versatile processor to subset and regrid the loaded datasets, (4) performance metrics designed to assess and quantify model skill, (5) plotting routines to visualize the performance metrics, (6) a toolkit for statistically downscaling climate model simulations, and (7) two installation packages to maximize convenience of users without Python skills. RCMES website is maintained up to date with a brief explanation of these

components. Although there are other open-source software (OSS) toolkits that facilitate analysis and evaluation of climate models, there is a need for climate scientists to participate in the development and customization of OSS to study regional climate change. To establish infrastructure and to ensure software sustainability, development of RCMES is an open, publicly accessible process enabled by leveraging the Apache Software Foundation's OSS library, Apache Open Climate Workbench (OCW). The OCW software that powers RCMES includes a Python OSS library for common climate model evaluation tasks as well as a set of user-friendly interfaces for quickly configuring a model evaluation task. OCW also allows users to build their own climate data analysis tools, such as the statistical downscaling toolkit provided as a part of RCMES.

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1 Introduction

The anthropogenic climate change signal in the Earth system is not globally uniform. Instead, the magnitude and character of climate change, including long-term trends, year-to-year variability, and characteristics of extremes of key meteorological